Aerospace Technology Congress
11-12 October 2016, Solna, Stockholm

Aerodynamic Analysis of the Influence of Canopy Shape in the Supersonic Dorsal Intake Design.

P. D. Bravo-Mosquera*, A. Martins-Abdalla*, H. D. Cerón-Muñoz*, F. Catalano*

* Department of Aeronautical Engineering, São Carlos Engineering School-University of São Paulo, Avenida João Dagnone, 1100 - Jardim Santa Angelina, São Carlos, SP, Brazil.
(E-mail: *pdbravom@usp.br*; *pfalvaro@sc.usp.br*; *hernan@sc.usp.br*; *catalano@sc.usp.br*)

Abstract. This work presents a computational analysis of the performance of an air intake under the influence of the canopy shape on a non-conventional supersonic fighter aircraft. In a first instance, a Two-Dimensional mixed compression intake was designed, aiming to accept slightly more airflow than the used engine requires. Accordingly, it was selected the intake geometry that optimize the total pressure recovery and prevent internal boundary layer separation at the engine entrance. Then, the intake was top mounted in a fuselage, in order to analyze its performance changes. For the preliminary design of the supersonic intake, some geometric characteristics of an engine were taken into account. Therefore, the engine chosen for this analysis was the Volvo RM-12. Numerical simulations were carried out, solving 2D time-dependent Reynolds Average Navier Stokes (RANS) equations, to obtain higher numerical accuracy of the shock wave/boundary layer interaction in the supersonic intake flow. Regarding to the flow interaction of the canopy with the dorsal intake, two different positions on the fuselage were studied. Thereby, the canopy/fuselage integration produce a low-energy flow from the canopy to the dorsal-intake. Consequently, the performance of the dorsal-intake undergoes a few reduction. However, one position presents increases in the potential intake-engine compatibility problems, maintaining similar performance values according to the intake geometry.

Keywords: Air Intake, Canopy Shape, Fighter Aircraft, Dorsal-Intake, Numerical Simulations.

INTRODUCTION

Strategic and technological changes in the industry created a new world scene, motivating to the military forces to adapt their troops to these new conditions quickly. In this sense, the military aviation field is one of the most researched, because the technological revolution has boosted the continuous improvement in the aircraft design methodologies, in order to optimize all the systems that make up a fighter aircraft. As a result, the military forces have endured a constant pressure of the industry; because they are forced to get modern and competitive systems, being necessary maintain a great deal of research and continuous development (Owen *et al* 2010; Liangliang 2016).

The process to design an aircraft is divided into three main phases: conceptual, preliminary, and detail design. Each phase has its own unique characteristics, involving aerodynamics, propulsion and structural design, which restrict the entire aircraft design processes. (Raymer 1992). Many of these design limitations are related to the mission that the aircraft have to perform. In this way, the application of the constraint analysis allows to calculate the main performance characteristics of the aircraft in relation to each phase of flight. These features are: The Wing Loading (W/S) and the Thrust to Weight Ratio (T/W), which means that the engine performance, the wing geometry and the weights distribution are the parameters that have a great influence on thrust, fuel consumption and on the maximum cross section area of the aircraft. Therefore, in this specific case, a poor execution of the conceptual design phase of a fighter aircraft may lead to an increase in the wetted area and in the wave Drag in supersonic flight (Abdalla *et al* 2013). According to Mattingly *et al* (2002), the thrust calculated using the constraint analysis represents an ideal value, compared with the thrust when the engine is installed on the aircraft. Therefore, the integration of the power-plant system and the airframe induces forces on the aerodynamic surfaces, increasing even more the total Drag of the aircraft.

These "Self-Drag" forces, as were appointed by Goldsmith and Seddon (1993) and Whitford (1987) must be counterbalanced by the available thrust of the engine selected. Specifically, it is being discussed of the intake (Supersonic and Subsonic diffusers) and the nozzle of the power-plant system. In this way, the calculation of the "Self-Drag" forces allows to determine the real thrust required by the aircraft and consequently, the areas ratio for the correct mass flow required by the operation of the aircraft engine.

In this paper, only is studied the effect of the intake / airframe integration in a 2D CFD analysis, where the main objective is to analyze the aerodynamic effect of the canopy shape in the performance of an air intake, which was designed for a non-conventional fighter aircraft (Bravo-Mosquera 2016. In prep) (Fig. 1).

First of all, it was realized an extensive subjective analysis of the types of intakes that have been more implemented in the fighter jets, with its respective location on the fuselage (Bravo-Mosquera *et al* 2016). The above, in order to study the main advantages of each type and select the intake that represents the best performance, in relation to the typical phases in a combat mission (Sóbester 2007). As a result, a two-dimensional mixed-compression air intake was studied. After this, the condition to design the intake was selected according to the mission profile for fighter aircraft, developed by Nicolai *et al* (2010). Hence, the "Escape-Dash" phase in a typical combat mission was selected, because the aircraft accelerate to a high-speed dash of *Mach = 2* at the maximum ceiling. Therefore, a common jet engine loses *8%* of the free stream total pressure through the intake, suffering a reduction in thrust of *13%* and consequently a *5%* of increase in the fuel consumption (Whitford 1987). For this reason, the intake designed for this research aims to optimize the pressure recovery in this condition with a uniform distribution at the engine face.

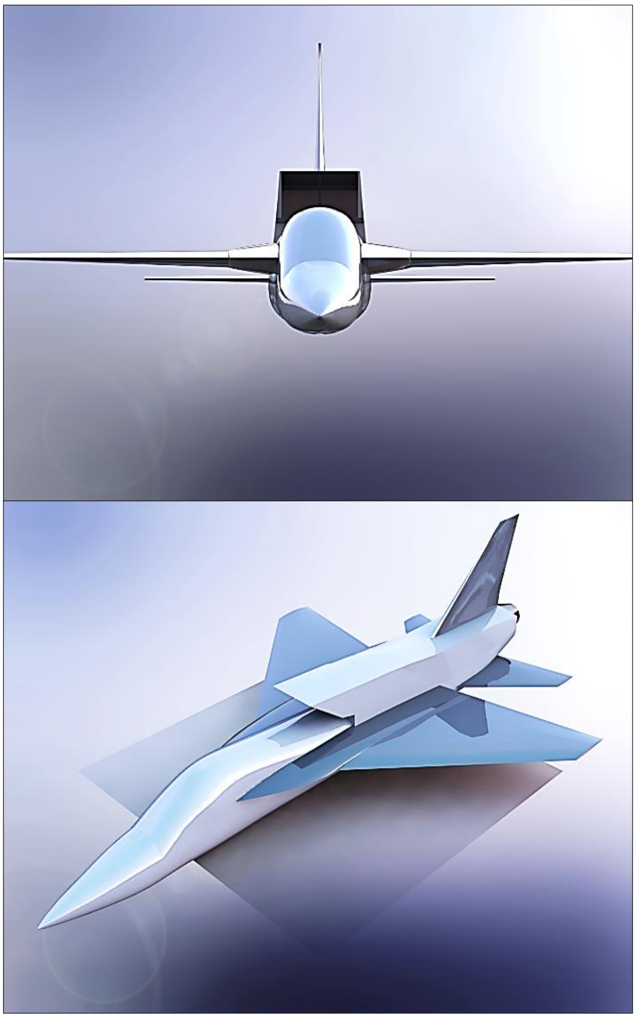

Figure 1: Geometric model of the fighter aircraft under study (Artistic Image).

To predict the intake performance, two-dimensional numerical simulations were implemented, in order to analyze the main aerodynamic characteristics of the intake designed analytically, as well as its respective position on the fuselage. For this, different studies of the mesh type, the boundary conditions and the turbulence model for the simulations were realized, aiming to obtain greater numerical accuracy of the shock waves/boundary layer interaction inside and outside the intake (Delery, 1985). The software used for the simulations was ANSYS - FLUENT 14.5 ®, which enables the imposition of approximated values of static pressure and temperature in the outlet of the subsonic diffuser, besides a set of interpolation parameters for the correct interpretation of the boundary conditions imposed (ANSYS, 2012).

OBJECTIVE

Some researches of modern fighter aircraft design have suggested that combat survivability might be improved by mounting engine intakes above the aircraft fuselage due to the reduction of the frontal aspect radar cross-section (RCS) (Williams *et al* 1981; Zichek 2008). Therefore, top-mounted intakes can reduce the aircraft weight and improve the weapon integration (Goldsmith and Seddon 1993; Watanabe *et al* 2010). On the other hand, the air intake system in a jet engine must satisfy an essential requirement; provide the correct amount of airflow to the engine face. This airflow should be free of distortions, with stability and being able to transform most of kinetic energy into energy due to pressure (Seddon and Goldsmith 1999). Above-mentioned, the main objective of this research is to study the performance changes of an intake, when it is top mounted on a fighter aircraft fuselage. For this, the geometry of the shock waves system for the air compression stage of the intake was remained fixed. Therefore, the subsonic diffuser used in the intake/airframe performance model was modified in its length, allowing the movement forward and backward in relation to the canopy aircraft, in two different locations, as shown in the Fig. 2. The entire intake set consists of the supersonic section, including the throat, the S-duct subsonic diffuser, the boundary layer diverter and the engine face (Fig. 3). The present study was developed to provide the correct quantity and quality of mass flow to the engine VOLVO RM-12. Therefore, some performance features of this engine were used, as the velocity and mass flow required at the engine face. (Larsson *et al* 1988).

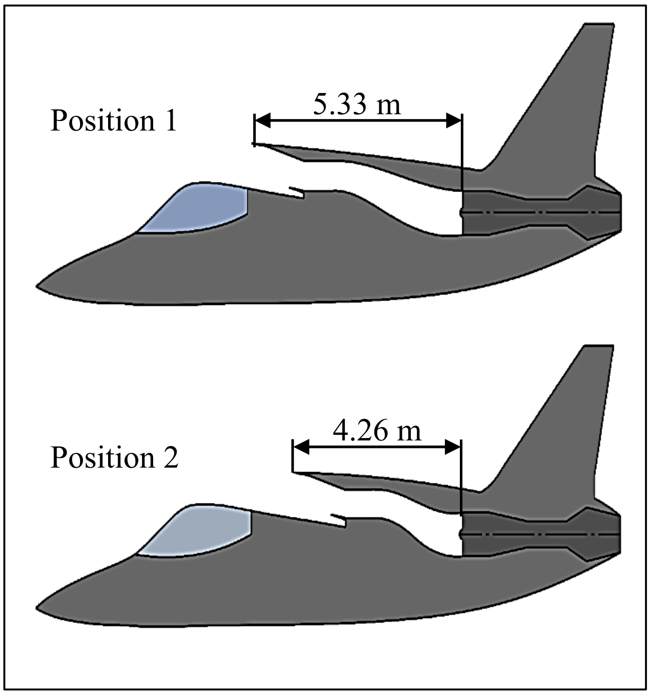

Figure 2: Intake/Airframe model.
Two Dorsal Intake Positions.

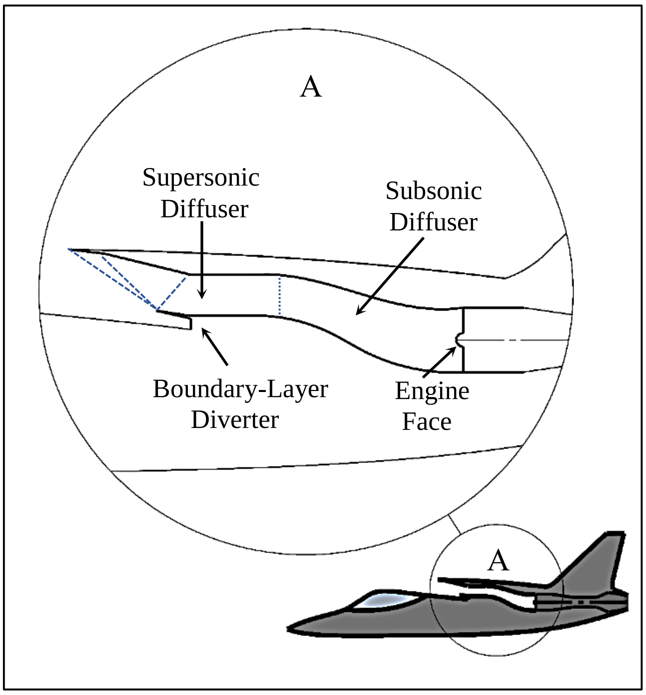

Figure 3: Detail of intake system.

METHODOLOGY

The design methodology of the intake flow path and its integration with a non-conventional fighter aircraft were used to develop a high efficient intake with different sizes of curvature in the subsonic duct. The main design principle is based on the slowdown of the mass flow from the supersonic diffuser to the engine entrance, through a multi-compression ramps system for the external oblique shock waves and a throat with constant cross-sectional area to stabilize the internal normal shock wave. The resulting configuration of the supersonic diffuser was used to design a curvilinear subsonic diffuser (S-duct).

Aerodynamic design of the intake

The intake was designed for maximum demand of the engine operation, including a margin of 4 % in the envelope of the flight mission. The external air compression system consists of two ramps with turning angles of 7 degrees respectively, at the on-design condition. The third ramp represents the cowl lip. It was chosen with straight leading edge and deflection angle of 8 degrees for matching the shocks at flowing over the swept bleeding wedge. The ramps angles selected must provide the maximum theoretical total pressure recovery at the intake for the widest possible range of free stream Mach numbers, according to the military specification MIL-E-5008B. (Mattingly *et al* 2002; Ran and Mavris 2005).

After the supersonic section comes the intake throat, which represents the transition zone that ensures the reattachment of the boundary layer after the normal shock (Crosthwait *et al* 1967; Aziz *et al* 2013). Finally, the subsonic duct was designed to make viscous loss as small as possible by setting an ideal cross sectional area distribution in the two positions presented above. The shape of the subsonic diffuser was calculated using a two-dimensional coordinate system orthogonal to the centerline, regarding to a super-elliptical cross-sectional shape (Wendt 2004)

There is a preliminary bleed of the Boundary layer, through a diverter wedge. It was adopted to improve the aerodynamic performance by removing the boundary layer developed on the canopy and the ramps. It is located at a section of the external compression stage, under to the intake duct section. For more information about the intake design refers to Bravo-Mosquera *et al* (2016).

Canopy-fuselage / dorsal intake effects

The aim of any canopy design is to reduce the frontal area of the fuselage while providing the pilot with a comfortable seat and a large canopy to allow good visibility (Munjulury *et al* 2014). In this sense, it was necessary to investigate the different canopy shapes that improve the supersonic performance of the aircraft, giving less supersonic wave drag. (Abhiram *et al* 2015). Understanding that the intake performance is unstable to some changes to the local environment, it is might reasonably have foreseen the display of the geometry, shifting the

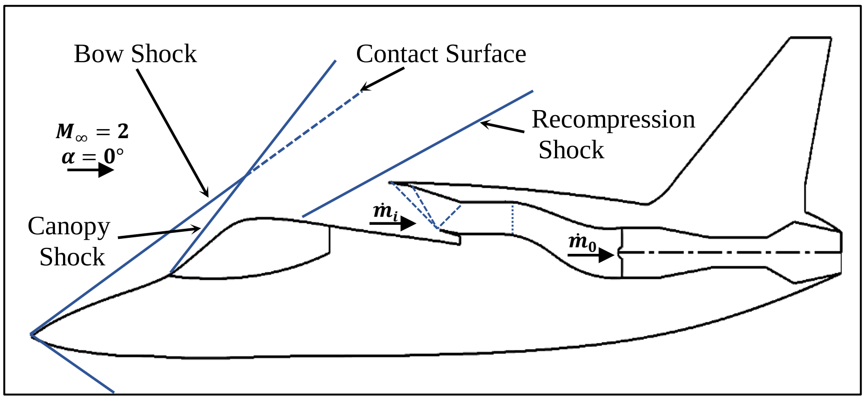

Figure 4: Intake/Fuselage Shock Interactions.

intake features and/or the level of the intake performance. Nevertheless, the two-dimensional intake demonstrated quite insensitive to geometry variation, when it is proved on fuselage/nose canopy integration, because of the changes in the free stream, due to the flow expansion around the canopy produced by the canopy shock, the bow shock and the recompression shock (Fig. 4) (Sanator 1970; Marcony and Salas 1973). On the other hand, the external flow field of an intake / fuselage integration is important since it determines not only the quality of air available to the engine, also the intake drag of the aircraft. This becomes even more important for a supersonic aircraft, because the internal flow field of an intake duct plays an equally important role in determining the quality of air (total pressure, Mach number and flow distortion) to the engine face (Marcony and Salas 1973; Richey *et al* 1983).

CFD Analysis

A two dimensional computational domain was created in order to simulate the aerodynamic behavior of the intake and its influence in the performance through the canopy integration. For this, the computational domain was dimensioned about 100 times the fuselage maximum diameter, in order to model free flight conditions, avoiding the far field pressure boundary to influence the pressure distribution in the vicinity of the intake / fuselage (Masud and Arkam 2010). Unstructured and structured meshing strategies were implemented for the fuselage and intake surfaces. Structured grids were used for the cells near the walls of the intake, in order to obtain higher numerical accuracy between the shock waves and the boundary layer. On the other hand, unstructured grids were used for the rest of the domain and the two subdomains created for the fuselage shock and the flow inside the intake (Fig. 5) (Kim *et al* 2011; Kanazaki *et al* 2004).

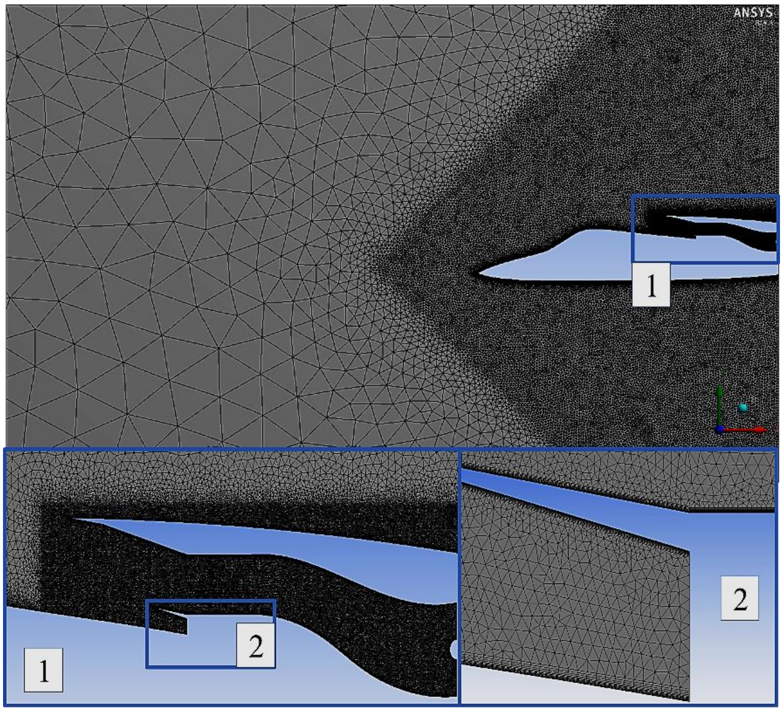

Figure 5: Computational Mesh Generated.

An independence mesh analysis was conducted in order to obtain an adequate number of elements to solve the flow phenomena, using the Reynolds Average Navier Stokes (RANS) equations. This reduced the computational cost by decreasing the time simulations. As a result, approximately $3.44e^{6}$ elements and $6.43e^{5}$ nodes were created. For this, the first layer of cells was set in $y = 1e^{-5}$, resulting in a $Y^{+} \approx 25$ at supersonic speeds. Figure 6 shows the independence mesh analysis for Mach number and Pressure distribution inside the intake system. For the present study, the two-equation Shear Stress Transport (SST) turbulence model, including the viscous work term were implemented due to its demonstrated feasibility for Aerospace applications, such as the present configuration (Kim and Song 2005). For boundary conditions, no-slip velocity condition was imposed at the surfaces / walls of fuselage and intake. Pressure / velocity boundary conditions were used at far field and fuselage base corresponding to the desired free stream Mach number and angle-of-attack. Pressure boundary condition was applied at intake duct outlet to control the intake mass flow rate (Mayer and Paynter 1994; Kim 2009; Das and Prasad 2010). Symmetry boundary condition was specified on the symmetry planes of the fuselage external domain and the intake internal domain. The bleed boundary condition was imposed trying the bleed region as a porous wall, extending from the front edge of the boundary layer diverter to the aft edge, with aperture ratio of 4% of the capture area (Mayer and Paynter 1994; Chyu *et al* 1992). The ANSYS-FLUENT-Solver was selected to solve the convergence criteria imposed, with the aim to reach the maximum residue adjusted in *1e-5* with a maximum number of iterations of *1500*.

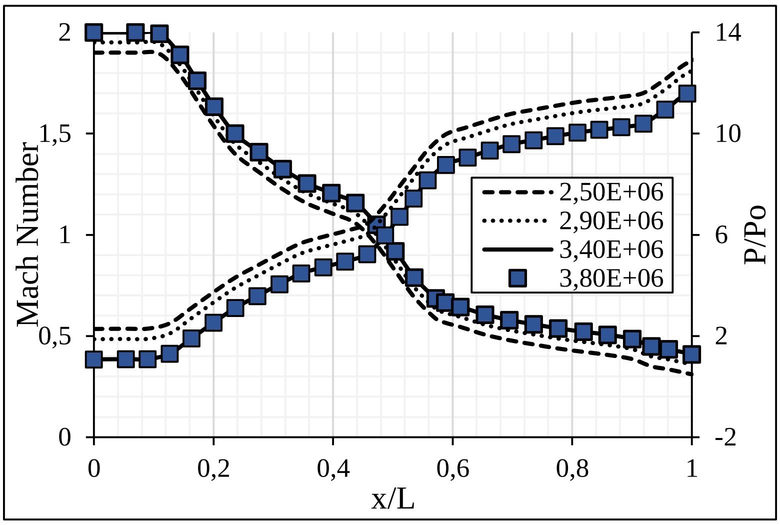

Figure 6: Independence Mesh Analysis.

RESULTS

The two positions of the intake for this analysis were chosen regarding to aircraft that have been designed with the same characteristics. In this way, the position 1 was selected according to the "North American F-107 Ultrasabre" aircraft and the position 2 was selected according to the "SAAB Project 2107" aircraft. To depict the basis of the proposed methodology, in this section is presented a performance analysis for the intake and the two positions of the dorsal-intake/fuselage integration, through the pressure recovery versus mass flow ratio and the distortion index evaluations at a given Mach numbers and zero attack angle (α) (On/Off-Design Conditions).

Total Pressure Recovery

The total pressure recovery *(η_σ)* was calculated using the (Eq. 1), indicating the efficiency of the mass flow entering to the engine face.

$$\eta_\sigma = \frac{P_A - P_\infty}{q_\infty} \tag{1}$$

Where: P_A, P_∞ and q_∞ represent average total pressure at the engine face station, free stream pressure and dynamical pressure respectively (Taeibi-Rahni *et al* 2004).

To predict intake performance properly, the shock interaction to the boundary layer and the detachment at the intake ramps should be calculated by a high order scheme. Therefore, the computational simulations were performed at four mass flows ratios ($\dot{m}_0/\dot{m}_i$) (95%, 85%, 75% and 65%). Figure 7 shows the comparison of the total pressure recovery of the intake-only configuration

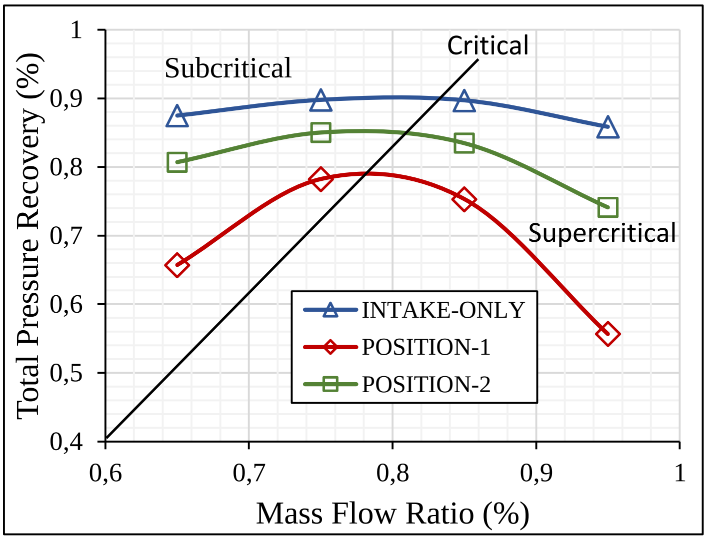

Figure 7: Mixed compression intake performance characteristics.

and the two intake/fuselage positions at the mass flow ratios described. The total pressure recovery is reduced at the critical point as the mass flow ratio decreased for each configuration. Nevertheless, the sub-critical operation range of the Position 2 is approximately 7% smaller than the intake-only configuration in comparison with Position 1, which is approximately 25%. This suggests that the position 2 of the intake/fuselage integration produces a more uniform flow to the engine face, becoming it in the most viable option to use in the aircraft. Furthermore, Fig. 8 and Fig. 9 show the Mach contour for the intake configuration and the position 2 at the on-design condition respectively. It can be seen that the normal shock wave is formed just at the entrance of the throat (Critical operation). Therefore, this condition provides better mass flow quality to the engine, due to the fraction of air spilled around the intake is minimum and the intake is matched to the engine.

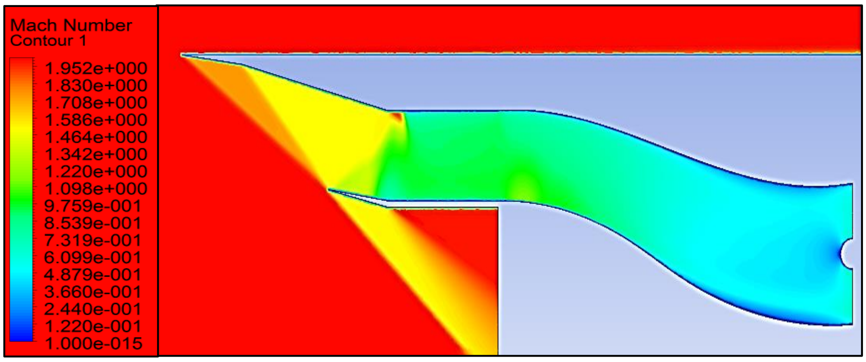

Figure 8: Mach contour for the intake configuration (Critical condition).

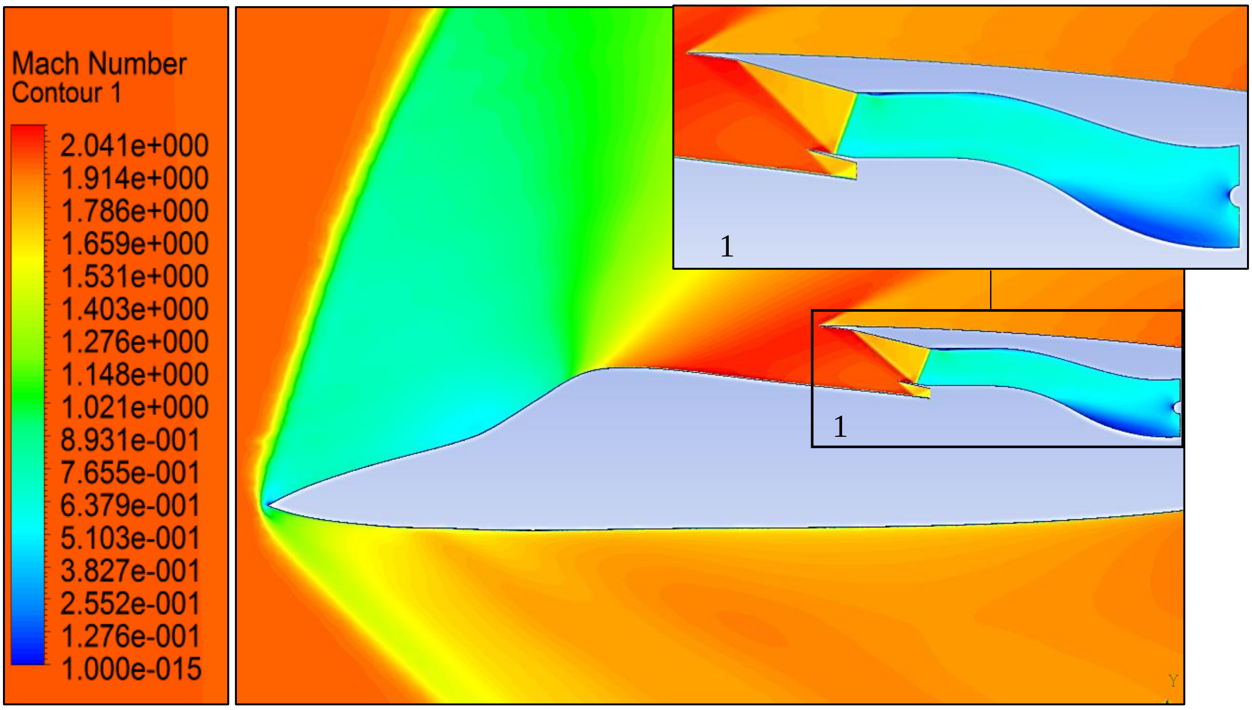

Figure 9: Mach contour for the position 2 (Critical Condition).

On the other hand, as it was expected, the intake-only configuration performs very well, with an abrupt supercritical phase and a critical total pressure recovery and mass flow ratio close to that predicted analytically. However, the integration of the intake with any of the positions causes a great demotion in performance (Lower thrust and higher specific fuel consumption). Understanding the above, the Fig. 10, Fig. 11 and Fig. 12 shows comparisons of the Mach number contours at supercritical condition for the three configurations evaluated. These figures show that the normal shock wave that appeared at the end of the throat moved downstream as the mass flow ratio increases, according to the Fig. 7. (Off-Design condition)

Figure 10 shows the Mach contour of the intake evaluated without integration, as can be seen, the normal shock is formed into the throat. This does not mean that the intake system is not efficient, because the mixed-compression intake was designed to operate in the supercritical regime. Therefore, the mass flow required by the engine arrives at a correct velocity, keeping high values of pressure.

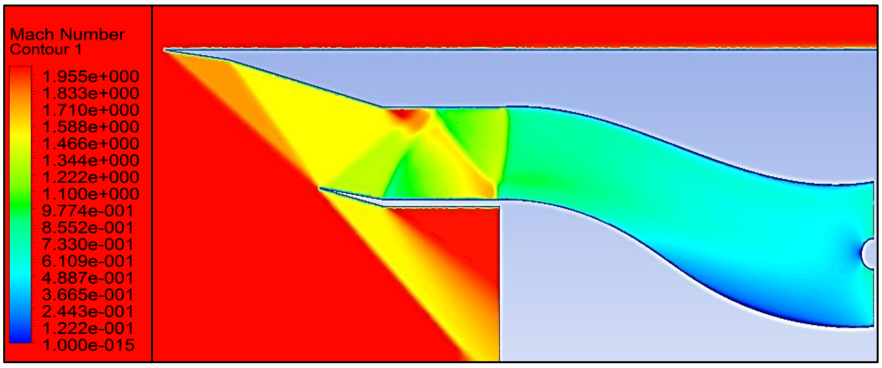

Figure 10: Mach contour for the intake configuration (Supercritical condition).

Figure 11 shows the Mach contour of the position 1, as can be seen; the normal shock is sucked down into the subsonic duct, because the intake cannot capture the mass flow rate required by the engine. Note that according to the Fig. 7, this position has a lower intake total pressure recovery associated to a reduction in the engine performance. In addition, this position has the longest subsonic duct. Therefore, this is the reason whereby greater fluid detachment and recirculation zones occurs, resulting in greater flow distortion at the engine face.

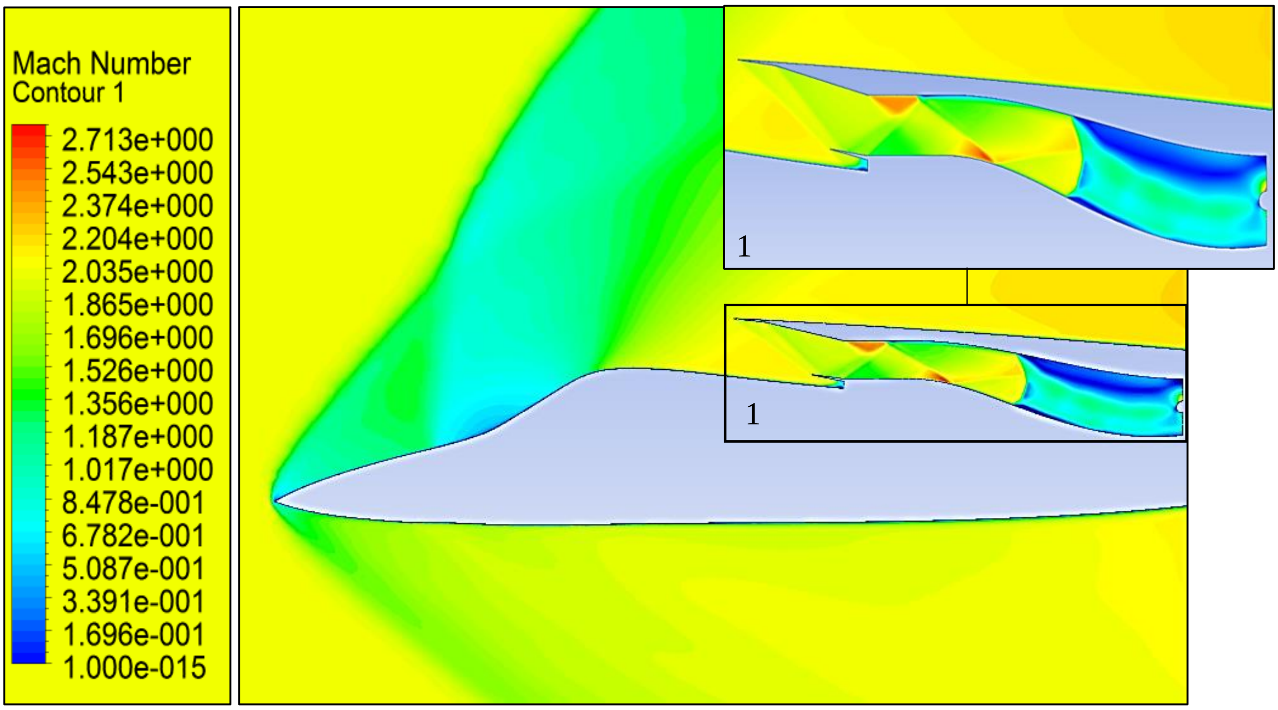

Figure 11: Mach contour for the position 1 (Supercritical Condition).

Finally, Fig. 12 shows the Mach contour of the position 2; in this case, the normal shock is formed at the end of the throat (Similar to the critical condition). However, due to the flow interaction between the canopy/fuselage and the intake, the intake provides more flow than the engine requires. Therefore, in this case, the excess air must bypass the engine to maintain the normal shock at its stable location and avoid the intake from unstarting (Driving out the normal shock wave).

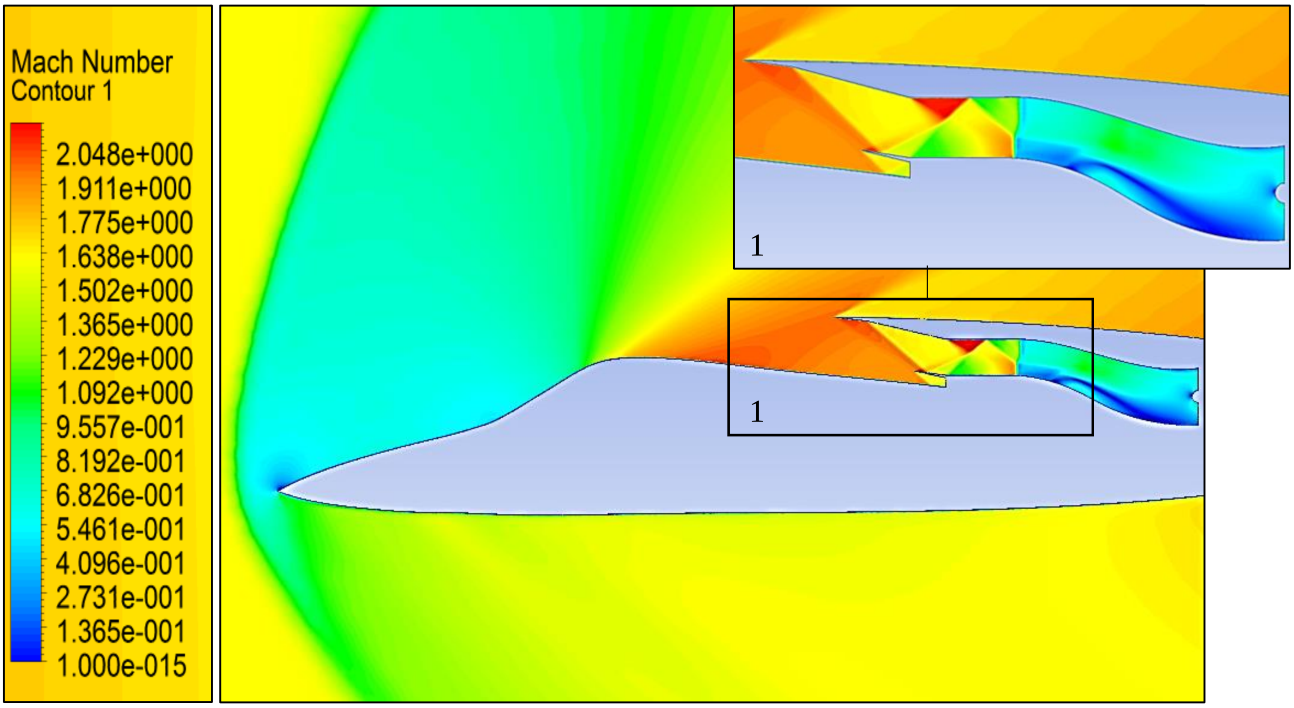

Figure 11: Mach contour for the position 2 (Supercritical Condition).

Distortion Index

In a 3D analysis, the distortion index is described as a distortion average on the rings of the compressor face of the engine. However, for this 2D research, the (Eq. 2) is used as follows:

$$D_I = \frac{P_{MAX} - P_{MIN}}{P_A} \qquad (2)$$

Where: P_{MAX}, $P_{MIN,}$ and P_A represent maximum total pressure, minimum total pressure and average total pressure at the engine face station. (Taeibi-Rahni *et al* 2004).

Table 1 shows the distortion index obtained for the three configurations studied.

Table 1. Computational distortion index.

Configuration	Intake-Only	Position 1	Position 2
Distortion Index (%)	6.8512	17.874	9.458

In terms of intake aerodynamics, it is evident that any loss of total pressure recovery, which occurs in a different manner than uniformity across the intake subsonic duct, resulting in a degree of distortion in the flow. Therefore, the interaction of the canopy shock and the boundary layer profile inside and outside the walls of the intake produce wall separation from high diffusion rates. This is the reason whereby the position 1 had a very high distortion coefficient in relation to the intake-only configuration and the position 2. In this way, the intake/engine compatibility if affected by the quality of the airflow delivered by the intake to the engine face, due to intake flow distortion.

CONCLUSIONS

A two-dimensional design and CFD analysis of the aerodynamic influence of a canopy-fuselage / dorsal intake integration were reported. During the design process, the integration of the intake with the fuselage was realized using two different positions, keeping the configuration of the supersonic diffuser and changing the geometry of the subsonic duct. According to the performance results, the position 2 represents the best performance and lowest distortion than the position 1, when these positions are compared with the performance of the intake itself.

In all, the shock interaction and the change of the centerline length of the subsonic duct produced a low energy flow, which decrease the pressure recovery in 18% and increase in 8.41 % the distortion index of the position 1, in relation to the position 2. On the other hand, the subcritical operation range of the two positions resulted in smaller values of pressure recovery, in relation to the intake-only configuration. This confirm that the presence of the canopy/fuselage affected the flow field inside the intake. However, the position 2 is the best location to be used in the aircraft, due to its close performance values in relation to the intake-only configuration.

Future studies will be realized in a 3D concept, because with the advent of vortex-lift generating devices on the fuselage and forward extension of the wing, some experimental studies have shown that it is possible to improve the quality and quantity of the intake mass flow by controlling the vortex pattern on the upper surface of the fuselage and thereby maintain acceptable flow quality to the intake over the mission of the aircraft.

REFERENCES

Abdalla, A., Gazetta, H., Grönstedt, T. & Krus P. 2013. The Effect of Engine Dimensions on Supersonic Aircraft Performance. In: *Proceedings of the 4th CEAS Air \& Space Conference*, Linköping, Sweden.

Abhiram, C., Neeraj, S., Abdul, R., Libin, G., Pathanjali, R., Muralidhar, M. & Subhendhu, S. 2015. Influence of Canopy Shape on the Supersonic Drag of a Generic Fighter Aircraft. In: *Proceedings of the 17th Annual CFD Symposium CFD Division.* Bangalore, India.

ANSYS Inc. 2010. *Solver Theory and Modeling Guide*. Canonsburg.

Aziz, M., Elbanna, H. & Abdelrahman, M. 2013. High Fidelity Design Optimization of a Three Dimensional Supersonic Intake. In: *Proceedings of the 43th Fluid Conference (AIAA),* San Diego, USA.

Bravo-Mosquera, P., Cerón-Muñoz, H. & Catalano, F. 2016. Analytical and Numerical Design of a Mixed-Compression Air Intake for a Supersonic Fighter Aircraft. In: *Proceedings of the 1º Simpósio de Engenharia Mecânica – Universidade de São Paulo,* São Carlos, Brazil.

Chyu, W., Howe, G. & Shih, T. 1992. Bleed-Boundary Conditions for Numerically Simulated Mixed-Compression Supersonic Inlet Flow. *Journal of Propulsion and Power*. **8(4)**, 862-868.

Crosthwait, E., Kennon, I. & Harry, L. 1967. Preliminary design methodology for air-induction systems. Technical Report SEG-TR-67-1, Systems Engineering Group.

Das, S. & Prasad, J. 2010. Starting Characteristics of a Rectangular Supersonic Air Intake With Cowl Deflection. *Aeronautical Journal*. **114(3)**, 177-189.

Delery, J. 1985. Shock Wave/Turbulent Boundary Layer Interaction and Its Control. *Progress in Aerospace Science*. **22(4)**, 209-280.

Goldsmith, E. & Seddon, J. 1993. *Practical Intake Aerodynamic Design*. American Institute of Aeronautics and Astronautics.

Kanazaki, M., Fujiwara, H., Ito, Y., Fujita, T., Obayashi, S. & Nakahashi, K. 2004. Numerical Simulation of Supersonic Intake Using Structured-Unstructured Zonal Approach. In: *Proceedings of the 24th International Congress of the Aeronautical Science*. Yokohama, Japan.

Kim, H., Takayasu, K., Sing, M., Povinelli, L. & Conners, T. 2011. Flow Simulation of Supersonic Inlet With Bypass Annular Duct. *Journal of Propulsion and Power*. **21(1)**, 29-39.

Kim, S. 2009. Aerodynamic Design of a Supersonic Inlet with a Parametric Bump. *Journal of Aircraft*. **46(1)**, 198-202.

Kim, S. & Song, D. 2005. Modeling Shear-Stress Transport Turbulence Model for Supersonic Flows. *Journal of Aircraft*. **2(5)**, 1118-1125.

Larsson, L., Beno, L. & Daub, W. 1988. Development of the F404/RM12 for the JAS 39 Gripen. In: *Proceedings of ASME International Gas Turbine and Aeroengine Congress and Exposition*. Amsterdam, Netherlands.

Liangliang, C., Kuizhi, Y., Weigang, G. & Dazhao, Y. 2016. Integration Analysis of Conceptual Design and Stealth-Aerodynamic Characteristics of Combat Aircraft. *Journal of Aerospace Technology and Management*. **8(1)**, 40-48.

Marconi, F. & Salas, M. 1973. Computation of Three Dimentional Flows about aircraft configurations. *Computers & Fluids*. **1(2)**, 185-195.

Masud, J. & Arkam, K. 2010. Flow Field and Performance Analysis of an Integrated Diverterless Supersonic Inlet. In: *Proceedings of the 48th AIAA Aerospace Sciences Meeting Including the New Horizons Forum and Aerospace Exposition*. Florida, USA.

Mattingly, J., Heiser, W. & Pratt, D. 2002. *Aircraft Engine Design*. American Institute of Aeronautics and Astronautics.

Mayer, D. & Paynter, G. 1994. Boundary Conditions for Unsteady Supersonic Inlet Analyses. *AIAA Journal*. **32(6)**, 1200-1206.

Munjulury, R., Staack, I., Abdalla, A., Melin, T., Jouannet, C. & Krus, P. 2014. Knowledge-based design for future combat aircraft concepts. In: *Proceedings of the 29th International Congress of the Aeronautical Science*. St. Petersburg, Russia.

Nicolai, L., Carichner, G. & Malcolm, L. 2010. *Fundamentals of aircraft and airship design.* American Institute of Aeronautics and Astronautics.

Owen, B., Lee, D. & Lim, L. 2010. Flying into the future: aviation emissions scenarios to 2050. *Environmental science & technology*. **44(7)**, 2255-2260.

Raymer, D. 1992. *Aircraft Design: A Conceptual Approach*. Washington DC: American Institute of Aeronautics and Astronautics.

Richey, G., Surber, L. & Berrier, B. 1983. Airframe-propulsion integration for fighter aircraft. *AIAA paper*, 83-0084.

Sanator, R. 1970. Investigation of Airframe-Inlet Interaction for Supersonic Tactical Fighter Aircraft. *Technical Report AFFDL-TR-70-66*. Wright-Patterson Air Force Base, Ohio. USA.

Seddon, J. & Goldsmith, E. 1999. *Intake aerodynamics*. American Institute of Aeronautics and Astronautics.

Sóbester, A. 2007. Tradeoffs in Jet Inlet Design: A historical Perspective. *Journal of Aircraft*. **44(3)**, 705-717.

Taeibi-Rahni, M., Soltani, M. & Taheri, A. 2004. *An introduction to intake aerodynamics*. Iranian aerospace research center publication, ministry of science, research and technology, Tehran.

Watanabe, Y., Ueno, A. & Murakami, A. 2010. Design of Top Mounted Supersonic Inlet for Silent Supersonic Technology Demonstrator S3TD. In: *Proceedings of the 27th International Congress of the Aeronautical Sciences*. Nice, France.

Williams, T., Nelms, P & Smeltzer, D. 1981. Top-Mounted Inlet System Feasibility for Transonic-Supersonic Fighter Aircraft. *NASA Technical Memorandum 81292*.

Whitford, R. 1987. *Design for air combat*. Jane's Information Group. UK.

Wendt, B. 2004. The performance of a Subsonic Diffuser Designed for high Speed Turbojet-Propelled Flight. NASA Contractor Report, CR. 213410. USA.

Zichek, J. 2008. North American FJ-5 Fighter: A Navalized Derivative of the F-107A. *American Aerospace Number 2.01 (ISSN 1943-9636).*